

BSTZ No. 003927P016
Express Mail No. EL802887545US

UNITED STATES PATENT APPLICATION

FOR

NARROWBAND INTERFERENCE CANCELLER
FOR WIDEBAND COMMUNICATION SYSTEMS

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CROSS REFERENCE TO RELATED APPLICATIONS

This non-provisional United States (U.S.) patent application claims the benefit of U.S. Provisional Application No. 60/290,378, filed by inventor Mehdi T. Kilani on May 11, 2001, titled "Narrowband Interference Cancellation For Wideband Communication Systems".

FIELD

This invention relates generally to communication methods, systems, and devices. More particularly, the invention relates to a filter for adaptively canceling interference in communication systems.

BACKGROUND

Receiving devices or systems in a communication system may receive signals or waveforms which are distorted by interference or noise. Some of the signal distortion may be caused by narrowband interference. Narrowband interference may be interfering noise or signals which are centered about particular frequencies.

Despite such interference, a receiving device must be able to detect a signal and determine its content. For example, the performance of spread spectrum communication systems such as Code Division Multiple Access (CDMA) and Orthogonal Frequency Division Multiplexing (OFDM) signals are severely degraded in the presence of strong sinusoidal interference.

Receiving devices use various methods, schemes, and/or systems to remove such interference. One such

method employs filters, such as a notch filter, to filter out interference from a received signal.

Notch filters remove signal energy contained in a narrow band of frequencies. A fixed frequency notch
5 filter removes a particular narrow band of frequencies. The narrow band of frequencies removed is determined by the value of the circuit elements employed in the filter.

However, in many applications, the particular
frequency of the interference is unknown and,
10 consequently, a fixed frequency notch filter is ineffective. Therefore, a filter which adapts itself to filter out interference of unknown or varying frequency is sought.

BRIEF DESCRIPTIONS OF THE DRAWINGS

Figure 1 illustrates a z-domain block diagram of a direct form II notch filter structure.

5 Figure 2 is a z-domain block diagram illustrating one structure of an adaptive notch filter as may be employed in one embodiment of the invention.

10 Figure 3 is a system-level diagram illustrating the structure of an adaptive algorithm as may be employed in one embodiment of the invention.

FIG. 3

DETAILED DESCRIPTION

In the following detailed description of the invention, numerous specific details are set forth in order to provide a thorough understanding of the invention. However, it will be obvious to one skilled in the art that the invention may be practiced without these specific details. In other instances well known methods, algorithms, procedures, components, and circuits have not been described in detail so as not to unnecessarily obscure aspects of the invention.

One aspect of the invention provides an adaptive notch filter to filter out interference in a signal. An adaptive structure is provided for eliminating a narrowband interference signal from the received signal prior to detection, thus improving the performance of the communication system significantly. The adaptive notch filter employs its output signal to generate a feedback error signal which serves to center the null frequency (filtered frequency band) of the notch filter on the narrowband interfering frequency.

Another aspect of the invention provides a novel notch filter structure with parameters that serve as absorbing scaling factors to reduce the dynamic range of the signals at the various nodes of the notch filter and provide stability to the filter.

An adaptive notch filter has an electrical control input to vary the null or center frequency (the narrow band of frequencies to be removed) of the notch filter.

According to one implementation, the invention utilizes a constrained Infinite Impulse Response (IIR) notch filter together with an adaptation algorithm in a novel structure. The adaptation algorithm may be a

recursive algorithm for updating the time varying coefficient(s) of the notch filter.

Figure 1 illustrates the z-domain block diagram of a direct form II notch filter structure 102. The filter 102 receives signal X[n] and provides a filtered signal Y[n].

Figure 2 illustrates the z-domain block diagram of one specific embodiment of the adaptive notch filter of the invention. The filter 202 receives as inputs signals x[n] and h[n] and provides a filtered output signal y[n]. Signal x[n] includes an information or data signal s[n] and an interference signal I[n]. The null or center frequency of the filter 202 is tuned by the adaptation signal or input parameter h[n] which itself is updated by an adaptive mechanism described below.

The filter transfer function is:

$$H(z) = a \frac{1 + k_1 k_2 h[n] k_5 z^{-1} + z^{-2}}{1 - a k_1 k_2 k_3 h[n] k_5 z^{-1} - a k_4 z^{-2}}$$

In order to provide the required stability without degrading the frequency response behavior of the notch filter 202, the coefficient "a" is introduced in the structure and is set to a value very close to unity. When implementing the system in integer arithmetic with finite word length, special care must be taken to reduce the dynamic range of the signals at various nodes of the filter. To do so, the parameters k1, k2, k3, k4, and k5 have been introduced in the system structure. These parameters serve as absorbing scaling factors to reduce the dynamic range of the signals at the various nodes. In one implementation, these parameters have values in the range of:

$$-1 \leq \frac{k_1}{2} k_2 k_3 h[n] \leq 1$$

$$0 < a < 1$$

$$0 < k_3, k_4 < 1$$

According to one embodiment, these parameters are
 5 set to integer power of 2^{-1} to simplify the notch filter
 implementation.

The value of $h[n]$ is updated using gradient-based
 algorithms such as Recursive Prediction Error and
 Pseudolinear Regression algorithms. The signals $w[n-1]$,
 10 $w[n-2]$, and $h[n]$ (shown in Figure 2) are scaled down by
 appropriate factors so that when the system is implemented
 in integer arithmetic, the dynamic range associated with
 each node always remains within the desired range. This
 prevents the structure from overflow non-linearity
 15 effects. As mentioned earlier, according to one
 implementation, all the coefficients 'a', k_1 , k_2 , k_3 , k_4 ,
 and k_5 are designed in the form of integer power of two to
 enable a computationally simple hardware structure.

The null or center frequency of the notch filter is
 20 allowed to vary adaptively using gradient-based algorithms
 such as Recursive Prediction Error (RPE) and Pseudolinear
 Regression (PLR). The adaptation is based on the
 minimization of the error signal which is the output
 signal $y[n]$ of the notch filter 202. Hence, no reference
 25 signal is required. Once convergence takes place, the
 null or center frequency of the notch filter is placed at
 the frequency corresponding to the unwanted narrowband
 interfering signal thus effectively eliminating the
 interference $I[n]$. The IIR filter structure is specially
 30 parameterized so that it remains stable within the whole
 input frequency range. This stability is achieved by
 selecting the value of coefficient 'a' to be less than but

close to unity. In conventional structures, the parameter 'a' is set equal to one (1) which makes the system prone to instability at frequencies very close to half the sampling frequency.

5 An advantage of the proposed structure is that no prior information regarding the frequency location of the interfering signal is required. That is, the adaptation signal $h[n]$, which serves to configure or set the null frequency of the notch filter, is based on the output
10 signal $y[n]$.

Figure 3 illustrates a block diagram of the structure 302 of an adaptive algorithm that may be employed in one embodiment of the invention. The adaptive algorithm is gradient based and its task is to minimize the power of
15 the signal at the output of the notch filter. Once the minimization has been accomplished, the null frequency of the notch filter is found at the frequency of the narrowband signal.

The error surface associated with this system is
20 proven to be unimodal provided that the desired wideband signal is corrupted with single narrowband interference. That is, the signal is corrupted by a single dominant interference narrowband. This means that the convergence of gradient-based algorithm is guaranteed and also the
25 minimum of the error surface corresponds to the interfering frequency line with a negligible bias.

The error signal and its derivative with respect to $h[n]$ are given by:

30 For RPE algorithm:

$$\begin{aligned}\frac{\partial e}{\partial h} &= w[n-2] \\ e[n] &= y[n-1];\end{aligned}$$

For PLR algorithm:

$$\frac{\partial e}{\partial h} = x[n-2];$$

$$e[n] = y[n-1];$$

5 The signals are delayed by one extra sample to reduce
the number of operations per cycle. The step size factor
is absorbed inside the scaling coefficients m1, m2 and m3.
In one implementation, these parameters are designed to be
integer power of 2⁻¹ to simplify the implementation further
10 and to reduce the dynamic range of the signals at various
nodes. The required frequency resolution, interference to
signal ratio improvement factor depend on the word length
of the adaptive coefficient h[n]. The bandwidth is
controlled by the parameters k3 and k5. The proposed
15 structure is able to place the null frequency of the notch
filter within a frequency band ranging from 0.004
(normalized frequency) to half the sampling frequency.

It must be understood that the adaptive notch filter
described herein is not limited to any particular
20 communication protocol or scheme and may be implemented on
both wired and wireless communication, transmission,
and/or reception systems.

Moreover, the adaptive notch filter is not limited to
any particular frequency or range of frequencies.
25 The proposed structure shown in Figure 2 is capable of
removing single narrowband interference, however multiple
filters embodying the adaptive filter describe herein may
be configure in series to remove more than one
interference signal.

30 As a person of ordinary skill in the art will
recognize, a narrowband is merely narrow relative to the

overall width of the communication channel employed.
Thus, the width of narrowband interference need not be
narrow in absolute terms but just in relative terms.

Additionally, various aspects of the invention are
5 novel over the prior art. For instance, no prior
information regarding the interfering frequency is
required with the adaptive notch filter described.
Moreover, the parametrization described makes the structure
highly stable with minimized dynamic range for signals at
10 various filter nodes. Also no reference signal is
necessary for the adaptive structure described, whereas
conventional interference cancellers based on the finite
impulse response (FIR) filter structure require a
reference signal to be available for effective
15 cancellation.

While certain exemplary embodiments have been
described and shown in the accompanying drawings, it is to
be understood that such embodiments are merely
illustrative of and not restrictive on the broad
20 invention. The invention is not limited to the specific
constructions and arrangements shown and described since
various other modifications may occur to those of ordinary
skill in the art. Additionally, it is possible to
implement the present invention or some of its features in
25 hardware, programmable devices, firmware, integrated
circuits, software or a combination thereof where the
software is provided in a processor readable storage
medium such as a magnetic, optical, or semiconductor
storage medium.

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